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PROBLEM OF GENERALIZING EXPERIMENTAL DATA ON HEAT TRANSFER IN THE VICINITY OF THE FORWARD STAGNATION POINT OF A CYLINDER POSITIONED PERPENDICULAR TO THE FLOW

Ye. P. Dyban, E. Ya. Epik and L. G. Kozlova

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16. Abstract

An investigation is made of the influence of the Reynolds number and the degree and scale of turbulence upon heat exchange at the forward critical point in turbulent flow. It is found that there is a great scatter of the experimental data.

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PROBLEM OF GENERALIZING EXPERIMENTAL DATA ON HEAT TRANSFER IN THE VICINITY OF THE FORWARD STAGNATION POINT OF A CYLINDER POSITIONED PERPENDICULAR TO THE FLOW

Ye. P. Dyban, E. Ya. Epik and L. G. Kozlova

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Many experimental studies have shown that, with an increase in the degree of turbulence of the external flow, there is a great intensification of heat exchange over the entire frontal surface of bodies (cylinder, sphere) positioned broadside to the flow, particular in the vicinity of their forward critical point. It is very difficult to generalize the experimental data due to the lack of a model, which has a valid theoretical and experimental basis, for the influence of the external flow turbulence upon convective heat exchange. This has led to the appearance in the literature of several recommendations which contradict each other on the selection of a method for evaluating this process quantitatively. The studies [6-8] propose generalizing the results of experiments on heat exchange at the forward critical point of a cylinder in the form of the dependence

$$\frac{\mathrm{Nu}}{\sqrt{\mathrm{Re}}} = f(\mathrm{Tu}\sqrt{\mathrm{Re}}). \qquad (1)$$

This dependence in [6, 8] is substantiated by the assumption that the intensification of heat exchange in the given case is related to the influence of vortices produced in the boundary layer close to the stagnation line under the influence of the

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* Numbers in margin indicate pagination in original foreign text.

turbulence of the external flow. The distance between the vortices (wavelength) is inversely proportional to the Reynolds number. In [7] a similar generalized dependence is obtained on the basis of the numerical solution of boundary layer equations, with which it is assumed that turbulent viscosity and heat conductivity change linearly over the thickness of the layer. On the basis of the general assumptions of similarity theory, the study [5] assumes that the turbulent Reynolds number is one of the decisive criteria and uses the following relationship for processing the experimental data.

$$\mathrm{Nu}_{\mathrm{Tu}} = \varepsilon_{\mathrm{Tu}} \mathrm{Nu}_{\mathrm{Tu}=0} = f(\mathrm{Re}_{\mathrm{Tu}})\, \mathrm{Nu}_{\mathrm{Tu}=0}. \quad (2)$$

The approach is more general which assumes that the decisive criteria are the characteristics of the flow turbulence, and in turn, the degree of turbulence and the relative scales (integral and dissipative), i.e.,

$$\mathrm{Nu} = f(\mathrm{Re},\ \mathrm{Tu},\ L_{\infty},\ \lambda_{\infty}). \quad (3)$$

The USSR Institute of Technical Thermal Physics of the Academy of Sciences made detailed studies of the local heat exchange of a cylinder positioned broadside to the flow in a flow agitated by air with differing degrees and scales of turbulence. In this investigation, the primary attention was given to studying the influence of the Reynolds number, and the degree and scale of turbulence, upon heat exchange at the forward critical point. The experiments were performed in a wind tunnel having a circular cross section with a diameter of 51 mm with blockage of q = 0.25. The cylinder to be tested with a diameter of 10 mm was heated by means of a Permalloy foil placed on its surface with a thickness of 0.03 mm and a width of 3 mm. Thus, if we disregard the transverse return flows of the body, the boundary conditions corresponded to a constant heat flow (the specific resistance of the foil at 20 - 100° C remained almost constant). In all of the experiments, the temperature head in the vicinity of the forward vertical point was maintained approximately constant. The turbulence characteristics were changed by means of perforated washers with a different number of openings, which changedthe flow turbulence degree between 2-26% (the longitudinal and transverse velocity pulsation components were practically equal), the longitudinal integral turbulence scale L_∞ = 3.5 - 16.5 mm, and the microscale λ_∞= 2-3 mm at Re = $3.10^3 - 7 \cdot 10^4$. Some of the measurements were performed under the conditions of a stabilized turbulent flow in a wind tunnel of a diameter of 51 mm at a distance of 80 calibers from the input, where the degrees of turbulence and the integral scale were 3-4% and 36 mm, respectively, in the section studied at Re - $4.5 . 10^3 - 5.2 \cdot 10^4$ [1]. The studies [3,4] give more detailed characteristics of the experimental equipment, the measurement method and the processing of the results. / 58

Figure 1 gives the data on heat exchange at the forward critical point as a function of the Reynolds number and the flow degree of turbulence. The experimental data in these figures are scattered with respect to the degree of turbulence (Figure 1 a) and the Reynolds number (Figure 1 b). It may be seen from Figure 1 b that the change in the degree of turbulence has the same influence upon the heat exchange at the forward critical point as does a change in the Reynolds number. For example, a change in the degree of turbulence of the incoming flow from 3 to 30% leads to an increase in the Nusselt number, respectively, from 50 to 74, i.e., by 48%. A change in the Reynolds number from $3.5 \cdot 10^3$ to $3.5 \cdot 10^4$ causes the heat exchange to be intensified by 48% (from 230 to 340).

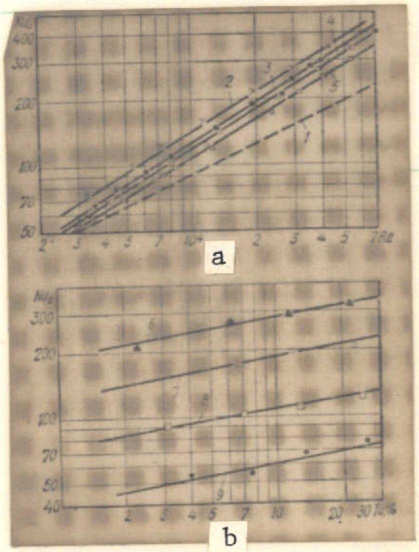

Figure 1. Heat exchange at the forward critical point as a function of:

a- Reynolds number; b- degree of turbulence of the external flow;

1- $NU_{Tu = 0} = 0.945\ RE^{0.5}$;

2- Tu = 21 - 26%; 3- 11 - 14%;

4- 6 - 8%; 5- 2 - 4%;

6- Re = $3.5 \cdot 10^3$.

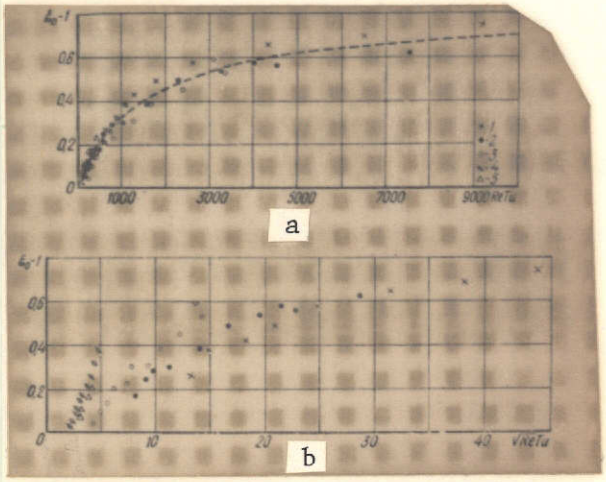

Figure 2. Heat exchange at the forward critical point as a function of:

a- ReTu; b- $\sqrt{Re}$Tu;

1- Tu - 21÷26%, L_∞/d = 1.65;

2- Tu = 11÷14%; L_∞/d = 1.1;

3- Tu = 6÷ 8%, L_∞/d = 0.63;

4- Tu = 2 ÷ 4%, L_∞/d = 0.35;

5- Tu = 3 ÷ 4%, L_∞/d = 3.6 in tunnel l/d = 80.

Figure 2a gives the results of measurements of heat exchange given in the form of the ratio of ε_0 — the Nusselt numbers at the forward critical point in an agitated flow Nu_0 — to their values for zero turbulence $Nu_{Tu = 0}$ as a function of Re Tu. The values of $Nu_{Tu = 0}$ are determined according to the criterial equation

$$Nu_{Tu=0} = 0{,}945\ Re^{0.5}. \qquad (4)$$

With a scatter in the values of ε_0 to ± 5%, the experimental data in the Reynolds number range $3 \cdot 10^3 - 7 \cdot 10^4$ and the degree of turbulence 2 - 26%, given in Figure 2a, are generalized by the experimental relationship [2]

$$\varepsilon_{a} = \frac{Nu_{\varphi}}{Nu_{Tu=0}} = 1 + \frac{0.8\,ReTu}{1500 + ReTu} \quad (5)$$

The experimental data shown in Figure 2a show that a change in the longitudinal integral turbulence scale from 3.5 to 36 mm (i.e., a change in $\frac{L_{\infty}}{d}$ from 0.35 to 3.60) has no great influence upon heat exchange in the vicinity of the forward critical point.

When these experimental data are processed in the form of the dependence on $\sqrt{ReTu}$ (see Figure 2b), there is a great scatter of the experimental points, particularly for low and moderate degrees of turbulence (up to 8%).

In spite of the fact that the data given are generalized somewhat better with respect to ReTu, the relatively small range of ReTu numbers makes it impossible to give an unequivocal answer to the question of which processing scheme is preferable. It must be kept in mind that allowance for the transverse return flows of the body may have an influence upon the distribution of the heat transfer coefficients over the cylinder perimeter, including the region of the critical point.

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